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TECHNICAL PROGRESS AND STRUCTURAL CHANGE[†]

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Abstract: In a recent paper Corden-Neary (CN) study the effects of technical progress on structural change in a small open economy. In this paper we discuss the issues raised by CN in the context of a two-country model in which capital of one country is used to extract the resources from the other labor-surplus country. We show that technical progress in the manufacturing sector of one country leads to a contraction in the manufacturing sector of the other country. Other implications of technical progress on sectoral development are also brought out.

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I. Introduction

In this paper we study the consequences of technical progress in one country for distribution of income and structural change in another, when both countries are linked to each other through international trade and investment and are part of a larger world economy. The essential novelty of our approach, in comparison with conventional theory, lies in our assumption that the two countries are asymmetric in that one, Industria, is a capital-rich, resource-poor economy whereas the other, Resourcia, is a capital-poor, resource-rich, labor-surplus economy.[1] In the terminology of Findlay [1982], ours is thus a North-South model[2] but we avoid this terminology in view of our assumption that Industria and Resourcia are small in the markets for manufactures and the primary resource.

Our model has particular relevance for studying the economic relations between an advanced, industrialized country and its newly-independent former colony. In such a situation, the latter's independent status allows it to trade the primary resource and manufactures in international markets. It also allows it to borrow capital in the international market but empirical evidence[3] suggests that by far the largest proportion of foreign invesment in the colonized country is by the colonizing country. Apart from the obvious historical links, such investment is justified on the twin count of cheap-labor and resource availability.[4] We thus assume that the two countries have mutually interpenetrated capital markets and that the rate of return to capital is endogenously determined.

Our work has tangential points of contact with two branches of the literature. First, it is similar in spirit to the recent investigation of the[5] "Dutch disease" by Corden-Neary [1982], henceforth CN. However, the difference with their study should be noted. They examine the consequences of technical progress for structural change in a small open economy whereas our two-country model brings into light production interdependence together with dependence through trade. Further, we allow international capital movements and assume surplus-labor in one country.

Our work also has a bearing on the controversy between inward-oriented versus outward-oriented development strategies; see Prebisch [1950], Singer [1950], Balassa [1982], among others. By formalizing explicitly the linkage between two economies, we can study how this dependence translates into changes in income of various classes and the consequences for industrialization of Resourcia.

The plan of the paper is as follows. The basic analytics of the model are presented in Section II. In Section III we analyze the effects of technical change on output levels of the two economies. The results are summarized in Section IV.

II. The Model and Preliminary Analysis

There are two countries, Industria and Resourcia, each being endowed with positive amounts of capital and labor. There are three commodities, a primary resource z, a manufactured good u and a traditional consumption good, say food, f. We assume Industria to be completely specialized in the production of u whereas Resourcia produces all the three commodities. We justify Resourcia's production of u as its attempt to industrialize.

We assume that u and z are internationally traded but that f is a non-traded commodity. The introduction of the f sector is to draw attention to the fact that the primary goods sector competes for purely domestic resources with traditional domestic industries and, as such, its expansion constrains and is constrained by the presence of such a sector.[6] Such a purely domestic resource is land and it is used in the production of f and z. Commodity z is produced with land, labor and capital and it is used as an intermediate input in the production of commodity u in both countries. Labor is used in the production of all three commodities and Industrian capital flows only in the z and u sectors of the Resourcian economy.

Let X_i stand for the level of production of the ith commodity which is produced in accordance with a well-behaved[7] linear homogeneous production function. Then

$$X_z = F_z(L_r, K_r, N_r) \tag{2.1}$$

$$X_u = F_u(L_u, K_u, M_u) \tag{2.2}$$

$$X_u^* = F_u^*(L_u^*, K_u^*, M_u^*) \tag{2.3}$$

$$X_f = F_f(L_f, N_f) \tag{2.4}$$

where K_i, L_i, M_i and N_i stand for capital, labor, the primary resource and land respectively, i = u, u*, z, f.

It is clear that material balance requires

$$K_z + K_u + K_u^* = K + K^* = K \tag{2.5}$$

$$N_z + N_f = \bar{N} \tag{2.6}$$

$$L_u^* = \bar{L}_u^* \tag{2.7}$$

$$L_z + L_u + L_f = L_e \tag{2.9}$$

where K* and K represent total endowments of capital in the two countries, $\bar{N}$ the total land in Resourcia, $\bar{L}^*$ the total labor force in Industria, and L_e the effective employment level in Resourcia. Observe that capital is internationally mobile whereas labor is internationally immobile, but mobile intersectorally within a country.

Given constant returns to scale, we can write down the cost functions[8] as

$$\bar{P}_z = C_z(\bar{w}, R, \tau) \tag{2.10}$$

$$P_f = C_f(\bar{w}, \tau) \tag{2.11}$$

$$\bar{P}_u = C_u(\bar{w}, R, \bar{P}_z) \tag{2.12}$$

$$\bar{P}_u^* = C_u^*(w^*, R, \bar{P}_z). \tag{2.13}$$

Given our assumption of small open economy, the commodity prices of the traded goods are given, i.e., $\bar{P}_z$, $\bar{P}_u$, $\bar{P}_u^*$ where $\bar{P}_u = \bar{P}_u^*$. $\bar{w}$ is the given subsistence wage rate in Resourcia. R is the rate of return on capital, τ the rate of return on land, w* the Industrian wage rate and P_f the price of the non-traded good.

In order to understand the effect of technical progress on the endogenous variables, we rewrite equations (2.5) to (2.9) in terms of input-output coefficients. Let C_{ij} denote the requirement of the ith

input per unit of the jth good, i = K, L, M, N and j = u, u*, f, z. We then have

$$C_{Ku}X_u + C^*_{Ku}X^*_u + C_{Kz}X_z = K + K^* = K \tag{2.14}$$

$$C_{Nz}X_z + C_{Nf}X_f = \bar{N} \tag{2.15}$$

$$C^*_{Lu}X^*_u = \bar{L}^*_u \tag{2.16}$$

$$C_{Lu}X_u + C_{Lz}X_z + C_{Lf}X_f = L_e \tag{2.17}$$

With quasi-concave and linearly homogeneous production functions, each C_{ij} is a function solely of input prices and is homogeneous of degree zero in all input prices.

The first point to be noted about our equilibrium is that prices are independent of endowments of capital and labor and depend solely on $\bar{w}$, $\bar{P}_u$ and $\bar{P}_z$. This is simply the observation that (2.10) - (2.13) is a system of four equations in four unknowns. (2.12) solves for R which gives us the value of τ from (2.10). (2.11) yields P_f and (2.13) w*. In this model, the price of the non-traded good, P_f, along with other prices is determined from conditions of profit maximization and thus changes in prices brought about by technical change is independent of demand conditions in the non-traded good sector. (This model is thus comparable to the model laid out in Section IV in CN.) However, demand conditions do play a role in determination of output levels and allocation of resources. For simplicity we assume

$$\bar{w}L_e = P_f X_f \tag{2.18}$$

i.e., employed labor in Resourcia spends all their income on food. Rentiers and capitalists in Resourcia and capitalists and laborers in Industria consume the manufactured good and food which they import from the rest of the world. (2.18) together with (2.14) - (2.16) can be used to determine the output levels X_u, X_u^*, X_f and X_z. (2.17) then yields L_e.

As in a standard Heckscher-Ohlin-Samuelson trade model, changes in commodity and factor prices affect output levels through changes in factor intensities. Towards this end we differentiate (2.14) - (2.18) to obtain,

$$\lambda_{Ku}\hat{X}_u + \lambda_{Kz}\hat{X}_z + \lambda^*_{Ku}\hat{X}^*_u = \hat{K} - [\lambda_{Ku}\hat{C}_{Ku} + \lambda_{Kz}\hat{C}_{Kz} + \lambda^*_{Ku}\hat{C}^*_{Ku}] \quad (2.19)$$

$$\lambda_{Nz}\hat{X}_z + \lambda_{Nf}\hat{X}_f = \hat{N} - [\lambda_{Nz}\hat{C}_{Nz} + \lambda_{Nf}\hat{C}_{Nf}] \quad (2.20)$$

$$\lambda^*_{Lu}\hat{X}^*_u = \hat{L}^* - \lambda^*_{Lu}\hat{C}^*_{Lu} \quad (2.21)$$

$$P_f X_f \hat{X}_f - wL_f\hat{X}_f - wL_u\hat{X}_u - wL_z\hat{X}_z = w[L_u\hat{C}_{Lu} + L_f\hat{C}_{Lf} + L_z\hat{C}_{Lz}] - P_f X_f \hat{P}_f \quad (2.22)$$

where a hat (^) denotes a rate of change (e.g., $\hat{K} = dK/K$) and where λ_{ij} is the proportion of the total supply of the ith factor used in the jth sector (e.g., $\lambda_{Ku} = C_{Ku}X_u/K = Ku/K$).

In order to solve for changes in output levels resulting from changes in factor prices, it is necessary to express the change in each C_{ij} in terms of input prices. Noting that $\bar{w}$ and $\bar{P}_z$ are constants, as in Batra-Casas [1976], we have

$$\hat{C}^*_{Lu} = -\theta^*_{Ku}\sigma^{u*}_{KL}(\hat{w}^*-\hat{R}) - \theta^*_{Mu}\sigma^{u*}_{ML}\hat{w}^*$$

$$\hat{C}_{Nf} = -\theta_{Lf}\sigma^{f}_{LN}\hat{\tau}$$

$$\hat{C}_{Nz} = -\theta_{Lz}\sigma^{z}_{LN}\hat{\tau} + \theta_{Kz}\sigma^{z}_{KN}(\hat{R}-\hat{\tau})$$

$$\hat{C}_{Ku} = -\theta_{Lu}\sigma^{u}_{LK}\hat{R} - \theta_{Mu}\sigma^{u}_{MK}\hat{R}$$

$$\hat{C}_{Kz} = -\theta_{Lz}\sigma^{z}_{LK}\hat{R} - \theta_{Nz}\sigma^{z}_{NK}(\hat{R}-\hat{\tau}) \qquad (2.23)$$

$$\hat{C}^*_{Ku} = \theta^*_{Lu}\sigma^{u*}_{LK}(\hat{w}^*-\hat{R}) - \theta^*_{Mu}\sigma^{u*}_{MK}\hat{R}$$

$$\hat{C}_{Lu} = \theta_{Ku}\sigma^{u}_{KL}\hat{R}$$

$$\hat{C}_{Lf} = \theta_{Nf}\sigma^{f}_{NL}\hat{\tau}$$

$$\hat{C}_{Lz} = \theta_{Kz}\sigma^{z}_{KL}\hat{R} + \theta_{Nz}\sigma^{z}_{NL}\hat{\tau}$$

where θ_{ij} is the distributive share of the ith factor in the jth sector[9] and σ^{j}_{is} is the partial elasticity of substitution[10] between the ith and the sth factor in the jth industry, i = L, K, N; j = u, u*, z, f. For the analysis to follow we assume all the partial cross elasticities of substitution to be positive, i.e., that all factors are weak substitutes for each other. The signs of $\hat{C}_{ij}$ then depend on the direction of change in the factor prices with technical progress.

III. Technological Progress and Structural Change

In this section we analyze the effects of technical progress on the output levels of different sectors and its implications with respect to structural change. To borrow CN's terminology, the "resource movement effect" and the "spending effect" due to technical progress combine to determine changes in the output levels.

We shall only consider Hicks-neutral technical change[11] in the four different sectors of our economies. This implies that, depending on the sector that is experiencing technical change, the left hand side of the cost functions specified in (2.10) - (2.13) will get multiplied by a technology parameter t. Given the recursive structure of our model, the effects on prices of technical change in different sectors can be easily derived and are summarized in the following table.[12]

Changes in prices ↑

Sector experiencing technical progress ←	$\hat{R}$	$\hat{\tau}$	$\hat{P}_f$	$\hat{w}^*$
u	+	-	-	-
u*	0	0	0	+
f	0	0	-	0
z	0	+	+	0

Table 1: The effects of Hicks-neutral technical progress in different sectors on prices.

Consider, for example, technical progress in the manufacturing sector in Resourcia. Given wages and the price of the primary resource, the return to capital rises. Since the primary resource is a traded good, profit maximization requires τ to fall. This in turn leads to a cheapening of the non-traded good. For Industria, the wage rate of the fully employed labor force falls. Technical progress in any other sector however leaves the return to capital unchanged. For the non-traded good sector, factor prices are predetermined. Hence technical progress there leads to a cheapening of that good. (2.12) and (2.13) form an independent subsystem and a technical progress in Industria increases the wage rate of its labor force. Similarly, given the value of R from (2.12), technical progress in the resource producing sector in Resourcia raises the return to land τ, which in turn pushes up the price of the non-traded good.

Note that changes in factor prices resulting from technical progress could be derived independent of any assumption on ranking of factor intensities. However, changes in output levels due to changes in factor prices depend on ranking of factor intensities among different sectors and on the extent to which factors of production are substitutable.[13] For the latter, we have already assumed the inputs to be substitutes. As regards factor intensities, we assume that $K_u/L_u > K_z/L_z$.

Singer [1950] has observed that in plantations with foreign capital, $K_z/L_z > K_u/L_u$. Since domestic capital formation was negligible, the capital intensity in plantations clearly dominated that in domestic traditional industries. In our case, however, Industrian capital not

only flows to the resource producing sector but also into domestic manufacturing in Resourcia. Hence our assumption, as opposed to Singer's, is not totally unjustified.

In our analysis we do not require any other assumption on factor intensities because (i) L* is fully employed in specialized Industria; (ii) the primary resource is a traded good; (iii) labor is internationally immobile and (iv) the non-traded sector uses two inputs of which the supply of labor is unlimited.

Using the results of Table 1 and (2.23), we can show the direction of change in the factor intensities due to technical progress in different sectors (see Table 3). For example, technical progress in Industria raises w*, leading to a substitution away from labor towards capital and the primary resource, i.e., $\hat{c}^*_{Lu} < 0$ and $\hat{c}^*_{Ku} > 0$. The other entries can also be argued along similar lines and we will use them to determine the output effects.

Sector experiencing technical progress ↓ / Changes in factor intensities →	$\hat{c}^*_{Lu}$	$\hat{c}_{Nf}$	$\hat{c}_{Nz}$	$\hat{c}_{Ku}$	$\hat{c}_{Kz}$	$\hat{c}^*_{Ku}$	$\hat{c}_{Lu}$	$\hat{c}_{Lf}$	$\hat{c}_{Lz}$
u	+	+	+	-	-	-	+	-	?
u*	-	0	0	0	0	+	0	0	0
f	0	0	0	0	0	0	0	0	0
z	0	-	-	0	+	0	0	+	+

Table 3: Changes in factor intensities as a consequence of changes in factor prices resulting from technical progress in the different sectors.

Consider first the case that is comparable to CN, i.e., technical progress in the primary resource producing sector (energy sector in their model). With increased productivity of the factors of production, output of this sector, X_z rises. Since the wage rate is given and the return to capital is predetermined, the fruits of progress accrue to the owners of land, i.e., τ rises. This leads to a shift in land use, i.e., from food production to raw material production. Since land prices rise, price of food also rises reducing the welfare of Resourcian labor who consume only food.

For Industria, factor prices are unchanged and hence factor intensities are unaffected. Given full employment of labor in the only sector, Industrian output remains constant. This has an important implication for Resourcia since it results in no increased capital inflow to Resourcia.

The change in the output of the manufacturing sector in Resourcia depends on the technology in the Resourcian food and extractive sectors as well as on the relative share of land in those two sectors. If the share of land in the food sector is greater than that in the extractive sector, then "small" partial elasticities of substitution between land and labor in these sectors leads to a decrease in Resourcian manufactuing output. Specifically, we show in the Appendix that

$$\text{Max } (\sigma^{f}_{NL}, \sigma^{z}_{NL}\theta_{Nz}/\theta_{Nf}) < 1$$

is a sufficient condition for this result. Thus we confirm CN's finding that technical progress in the resource sector leads to "de-industralization." However, an opposite conclusion is also plausible. To show this, we limit ourselves to the special case of linear cost functions

in the Resourcian food and extractive sectors. We can then show (See Appendix) that with a "large" partial elasticity of the substitution between land and labor in the food sector, i.e.,

$$\sigma_{NL}^{f} > Le/Lz,$$

technical progress in the primary resource sector will raise manufacturing output in Resourcia. Thus, as opposed to CN, there is no necessary tendency for de-industrialization in our model, technical progress in the resource producing sector can lead to pro-industrialization.

It is important to appreciate why technical progress in the Resourcian extractive sector leads to a change in its manufacturing output inspite of there being no change in the factor prices this sector faces. The answer lies in the fact that the price of food and land rent do change, and given the general equilibrium setting, this leads, in particular, to a reallocation of capital use between the manufacturing and extractive sectors in Resourcia; see Table 3. As brought out in the Appendix, this reallocation leads to a variety of changes of unspecified directions, all influencing Resourcian manufacturing output.

In the introduction we emphasized the fact, that, technical progress in developed countries do have implications with respect to the growth pattern of developing and less developed countries. In this connection we now examine the effects of technical progress in Industria with respect to output and employment levels in Resourcia.

As already observed, technical progress in Industria only benefits Industrian labor in terms of increased wages. Output level X_u^* rises and there is a substitution away from labor towards capital and the primary resource which are now relatively cheaper than labor. This immediately implies an outflow of capital from Resourcia to Industria since we have one-to-one dependence. The primary resource is however available at a fixed price in the world market. Both the capital using sectors in Resourcia tend to shrink, but with an expansionary effect operating only on the primary resource producing sector in terms of increased demand. Given our assumption, $K_u/L_u > K_z/L_z$ a shrinkage in X_u releases enough capital to sustain an increase in X_u^* and X_z. An increase in X_z however requires increased amount of land which in turn leads to a fall in the output of food, X_f. Thus technical progress in Industria necessarily causes de-industrialization for Resourcia under our factor-intensity assumption. If the intensity ranking is reversed then it might cause de-industrialization. Further, given equation (2.18), a fall in X_f at constant prices implies a reduction in overall employment at constant wages. Thus technical progress abroad not only causes de-industrialization, it leads to an overall shrinkage of the Resourcian economy in terms of employment.

What remains to be examined are the implications of technical progress in Resourcian manufacturing and the sector producing the non-traded good. Let us consider the latter case first. As laid out in Table 1, technical progress in the f-sector only causes a cheapening of that good leaving all factor prices and hence factor intensities unchanged. The output of food, X_f rises increasing employment there

and also demand for land. This in turn causes the other land-using sector, the z-sector, to contract releasing land and capital. Since Industrian demand for capital is unchanged, Resourcian manufacturing expands with the capital released from the z-sector. Thus technical progress in the traditional sector will lead to industrialization and in its own growth at the expense of a shrinking primary resource producing sector.

Technical progress in the manufacturing sector in Resourcia changes all factor prices and techniques of production. The return to capital rises and all other prices fall. It is immediately clear that a reduction in w^* causes the welfare of Industrian labor to fall. With respect to output levels, X_u rises. Demand for capital rises which requires an increased inflow of capital either from Industria or from capital released from the z-sector. With an increase in R resulting in a decrease in w^*, there is a substitution away from capital in Industria. So X_u^* falls. This releases capital from Industria. X_z also falls. Since $K_u/L_u > K_z/L_z$, the reduction in X_z does not release sufficient capital to support the increase in X_u. This additional capital is available from a reduction in X_u^*.

As all factor prices change, the cost functions reveal that in the z-sector, labor and land becomes relatively cheaper leading to a substitution towards these inputs. Again for the f-sector, labor becomes relatively dearer, causing a substitution away from labor to land. It is thus clear from (2.18), that the effect on X_f cannot be unambiguously determined.

The output effects of technical progress are summarized below in Table 2.

Changes in output levels ↑

Sector experiencing technical progress ←

	$\hat{X}_u$	$\hat{X}^*_u$	$\hat{X}_f$	$\hat{X}_z$
u	+	-	?	-
u*	-	+	-	+
f	+	0	+	-
z	?	0	?	+

Table 2: Output effects of technical progress

IV. Summary of Results

In conclusion, we summarize the principal results of our paper.

1. Technical progress in Industrian manufacturing benefits Industrian labor but is inconsequential for capital of either country. The output of Industrian manufactures increases but that of Resourcian manufactures falls. Food production decreases while the production of the resource increases.

2. Technical progress in Resourcian manufacturing benefits capital and hurts Industrian labor. Production of the resource falls, the output of Resourcian manufactures rises and that of Industrian manufactures falls. The effects on the production of food are ambiguous.

3. Technical progress in the extractive sector is inconsequential for capital or labor in either country. However, it may lead to an

expansion or a contraction of Resourcian manufactures. Industrian manufactures remain unaffected while the effect on the production of food is ambiguous.

4. Technical progress in the Resourcian food sector only reduces the price of food. Production of the resource declines while that of Resourcian manufactures increases. Food production increases and Industrian manufactures remain unaffected.

In the language of CN, we have shown in the context of a two country model of international trade that technological progress in either the extractive sector or the manufacturing sector may not always cause "de-industrialization" for the country in which the extractive sector is located. The same is true of the food producing sector. We go a step beyond CN and also show that technical progress in a country which is resource dependent will cause "de-industrialization" for the country supplying the resource.

Footnotes

[1]For pioneering models of an asymmetric world economy, see Kemp-Ohyama [1978] and Findlay [1980]. The classic reference for a labor-surplus economy is, of course, Lewis [1954].

[2]For a survey of this literature, see Findlay [1982].

[3]See, for example, Bernstein [1968] and Widstrand [1975].

[4]See Bergsten et. al. [1978] and Drz-Alejandro [1979].

[5]Caves and Jones [L981, Section 6.5].

[6]This also makes our model comparable to Corden-Neary.

[7]We shall assume that the production functions are each twice continuously differentiable and strictly concave.

[8]For details as regards the dual formulation, see for example,

[9]For example, $\theta Lf = (wL_f/P_f X_f)$.

[10]For example, Allen [1971 p. 504].

[11]Extension to more general kinds of technical progress are straightforward, see, for example, footnote 1 in Neary [1981].

[12]The algebra is straightforward; consider for example, technical progress in the manufacturing sector in Resourcia. On multiplying the left hand side of (2.12) by t and differentiating (2.10) - (2.13) with respect to t, we obtain respectively

$$0 = \frac{\partial C_z}{\partial R}\frac{dR}{dt} + \frac{\partial C_z}{\partial \tau}\frac{d\tau}{dt}$$

$$\frac{dP_f}{dt} = \frac{dC_f}{d\tau}\frac{d\tau}{dt}$$

$$P_u = \frac{dC_u}{dR}\frac{dR}{dt}$$

$$0 = \frac{\partial C^*_u}{\partial R}\frac{dR}{dt} + \frac{\partial C^*_u}{\partial w^*}\frac{dw^*}{dt}$$

On using the fact that the cost functions are increasing in each argument, we obtain,

$$\frac{dR}{dt} = P/(dCu/dR) > 0$$

$$\frac{d\tau}{dt} = -\frac{\partial C_z}{\partial R}\frac{dR}{dt}\Big/\frac{\partial C_z}{\partial \tau} < 0$$

$$\frac{dP_f}{dt} = \frac{dC_f}{d\tau}\frac{d\tau}{dt} < 0$$

$$\frac{dw^*}{dt} = -\frac{\partial C^*_u}{\partial R}\frac{dR}{dt}\Big/\frac{\partial C^*_u}{\partial w^*} < 0$$

Hence $\hat{R} > 0, \hat{\tau} < 0, \hat{P}_f < 0, \hat{w}^* < 0$, and we have justified the entries of the first row of Table 1. The other entries can be similarly justified.

[13] See Batra-Casas [1976].

Appendix:

From Table 1, technical progress in sector z increase τ and P_f, but leaves R and w* unchanged. Using this information in (2.23) and substituting the results in expressions (2.19) - (2.22), we obtain:

$$\begin{bmatrix} \lambda_{ku} & \lambda_{Kz} & 0 & \lambda^*_{Ku} \\ 0 & \lambda_{Nz} & \lambda_{Nf} & 0 \\ 0 & 0 & 0 & \lambda^*_{Lu} \\ -\bar{w}L_u & -\bar{w}L_z & \tau_{Nf} & 0 \end{bmatrix} \begin{bmatrix} \hat{X}_u \\ \hat{X}_z \\ \hat{X}_f \\ \hat{X}^*_u \end{bmatrix} = \begin{bmatrix} -\lambda_{Kz}\hat{C}_{Kz} \\ -\lambda_{Nz}\hat{C}_{Nz} - \lambda_{Nf}\hat{C}_{Nf} \\ 0 \\ w(L_f\hat{C}_{Lf}+L_z\hat{C}_{Lz}) - P_fX_f\hat{P}_f \end{bmatrix},$$

where $\tau_{Nf} = P_fX_f - wL_f$. Let the 4 x 4 matrix be denoted by V; then

$$\hat{X}_u = \frac{1}{|V|} \begin{bmatrix} -\lambda_{Kz}\hat{C}_{Kz} & \lambda_{Kz} & 0 & \lambda^*_{Ku} \\ -\lambda_{Nz}\hat{C}_{Nz} - \lambda_{Nf}\hat{C}_{Nf} & \lambda_{Nz} & \lambda_{Nf} & 0 \\ 0 & 0 & 0 & \lambda^*_{Lu} \\ w(L_f\hat{C}_{Lf} + L_z\hat{C}_{Lz}) - P_fX_f\hat{P}_f & -\bar{w}L_z & \tau_{Nf} & 0 \end{bmatrix} \equiv \frac{|U|}{|V|}$$

$$|V| = \bar{w}\lambda_{Nf}\lambda^*_{Lu}(\lambda_{Kz}L_u - \lambda_{Ku}L_z) - \lambda_{Ku}\lambda^*_{Lu}\lambda_{Nz}(P_fX_f - \bar{w}L_f).$$

By demand condition (2.18), $P_fX_f > \bar{w}L_f$, and by our factor intensity assumption $K_u/L_u > K_z/L_z$, which implies $\lambda_{Ku}L_u - \lambda_{Ku}L_z = \frac{K_zL_u}{K} - \frac{K_uL_z}{K} < 0$. Hence $|V| < 0$.

$$|U| = -\lambda^*_{Lu}\{-\lambda_{Kz}\hat{C}_{Kz}\lambda_{Nz}\tau_{Nf} + \lambda_{Kz}\lambda_{Nf}[\bar{w}(L_f\hat{C}_{Lf}+L_z\hat{C}_{Lz}) - P_fX_f\hat{P}_f]$$

$$- \lambda_{Nf}\bar{w}L_z\lambda_{Kz}\hat{C}_{Kz} + \lambda_{Kz}\tau_{Nf}(\lambda_{Nz}\hat{C}_{Nz}+\lambda_{Nf}\hat{C}_{Nf})\}.$$

Using $\bar{w}(L_z+L_u+L_f) = P_fX_f$ from (2.18) and (2.9), we obtain

$$|U| = \lambda_{Kz}\lambda^{*}_{Lu}\,[\lambda_{Nz}\tau_{Nf}(\hat{C}_{Kz}-\hat{C}_{Nz}) + \lambda_{Nf}w(\hat{P}_f L_u+\hat{C}_{Kz}L_z) - \hat{C}_{Nf}\tau_{Nf}\lambda_{Nf}$$

$$+ \lambda_{Nf}\bar{w}L_z(\hat{P}_f-\hat{C}_{Lz}) + \lambda_{Nf}\bar{w}L_f(\hat{P}_f-\hat{C}_{Lf})]$$

By Table 3, the first three terms are positive.

By (2.11) $\hat{P}_f = \dfrac{dP_f}{P_f} = \tau\,\dfrac{\frac{\partial C_f}{\partial \tau}}{P_f}\,\dfrac{d\tau}{\tau} = \theta_{Nf}\hat{\tau}$ and

by (2.23), we have

$$\hat{P}_f - \hat{C}_{Lf} = \theta_{Nf}\hat{\tau} - \theta_{Nf}\sigma^{f}_{NL}\hat{\tau}$$

$$\hat{P}_f - \hat{C}_{Lz} = \theta_{Nf}\hat{\tau} - \theta_{Nz}\sigma^{z}_{NL}\hat{\tau}$$

Therefore, if $\sigma^{f}_{NL} < 1$ and $\sigma^{z}_{NL} < \dfrac{\theta_{Nf}}{\theta_{Nz}}$, $|U| > 0$ and we have $\hat{X}_u = \dfrac{|U|}{|V|} < 0$.

On the other hand, if the cost functions of resource and food product in Resourcia are linear,

$$\bar{P} = C_z(\bar{w},R,\tau) = \phi(\bar{w})(aR+b\tau)$$

$$P_f = C_f(\bar{w},\tau) = \psi(\bar{w})\,\tau$$

then $\dfrac{\partial C_z}{\partial R} = \dfrac{K_z}{X_z} = C_{Kz} = \phi(\bar{w})\,a$

$$\hat{C}_{Kz} = \frac{dC_{Kz}}{C_{Kz}} = 0$$

In a similar way, it can be shown that

$$\hat{C}_{Nz} = 0,\ \hat{C}_{Nf} = 0.$$

Therefore, we obtain

$$|U| = \lambda_{Kz}\lambda^{*}_{Lu}[\hat{P}_f\lambda_{Nf}P_fX_f - \hat{C}_{Lf}\lambda_{Nf}\bar{w}L_f - \hat{C}_{Lz}\lambda_{Nf}\bar{w}L_z].$$

By (2.11) (2.18) and (2.23)

$$|U| = \lambda_{Kz}\lambda^{*}_{Lu}\hat{\tau}\lambda_{Nf}\bar{w}[-\theta_{Nz}\sigma^{z}_{NL}L_f + \theta_{Nf}(L_e - \sigma^{f}_{NL}L_f].$$

If $L_e - \sigma^{f}_{NL}L_f < 0$, $|U| < 0$. Thus leads to $\hat{X}_u > 0$.

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